Present state of auxiliary methods of mountain tunnel construction in poor ground

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ABSTRACT

In tunnel excavation, the working face must remain stable until tunnel supports are in place and become effective. In cases, however, where ground conditions are poor and the working face does not support itself, an auxiliary construction method for face stabilization needs to be employed. In the construction of a large-section tunnel or an earth tunnel in an urban area, it is necessary to adopt a highly reliable auxiliary method of construction, taking into consideration safety in construction, certainty of success in construction, and environmental impacts. In the context of recent trends toward larger-cross-section tunneling, rationalization of construction, and environmental protection, face and ground stabilization measures are beginning to be regarded as important independent methods of construction rather than auxiliary measures.

In keeping pace with the development and implementation of new auxiliary construction methods, decisions as to which auxiliary methods to use or whether to adopt any auxiliary methods are becoming an important factor affecting the degree of rationalization that can be achieved. This paper reviews the present state of auxiliary construction methods for mountain tunneling in poor ground, focusing primarily on long steel pipe forepiling, which has been growing in usage in recent years, and reports on problems yet to be addressed.

1. MOUNTAIN TUNNELING METHODS IN RECENT YEARS

According to a report on examples of tunneling methods (NATM) based on survey results concerning major urban tunnel projects, the areas of application in which the shield tunneling method and NATM coexist are expanding.

Technological factors contributing to the expansion of the areas of application of NATM include research on investigation and design methods, such as preliminary investigation and numerical analysis, and the research and development of rational construction methods. However, the development and widespread use of various auxiliary construction methods such as the umbrella arch method is also an important contributing factor. The umbrella arch method is a method of enhancing the stability of the working face by forming an arch of ground support (presupport) along the tunnel perimeter prior to tunnel excavation (see Figure 1).

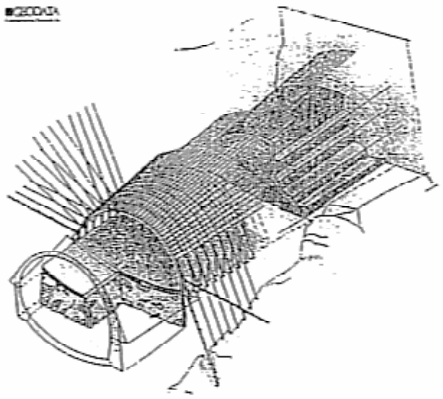

Fig.1 Steel Pipe unbrella arch

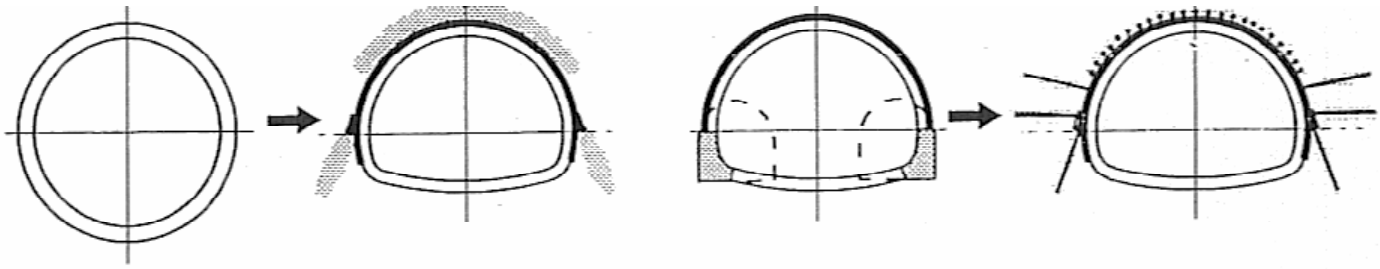

Fig.2 Changes in tunnel excavation methods effected by the umbrella arch method

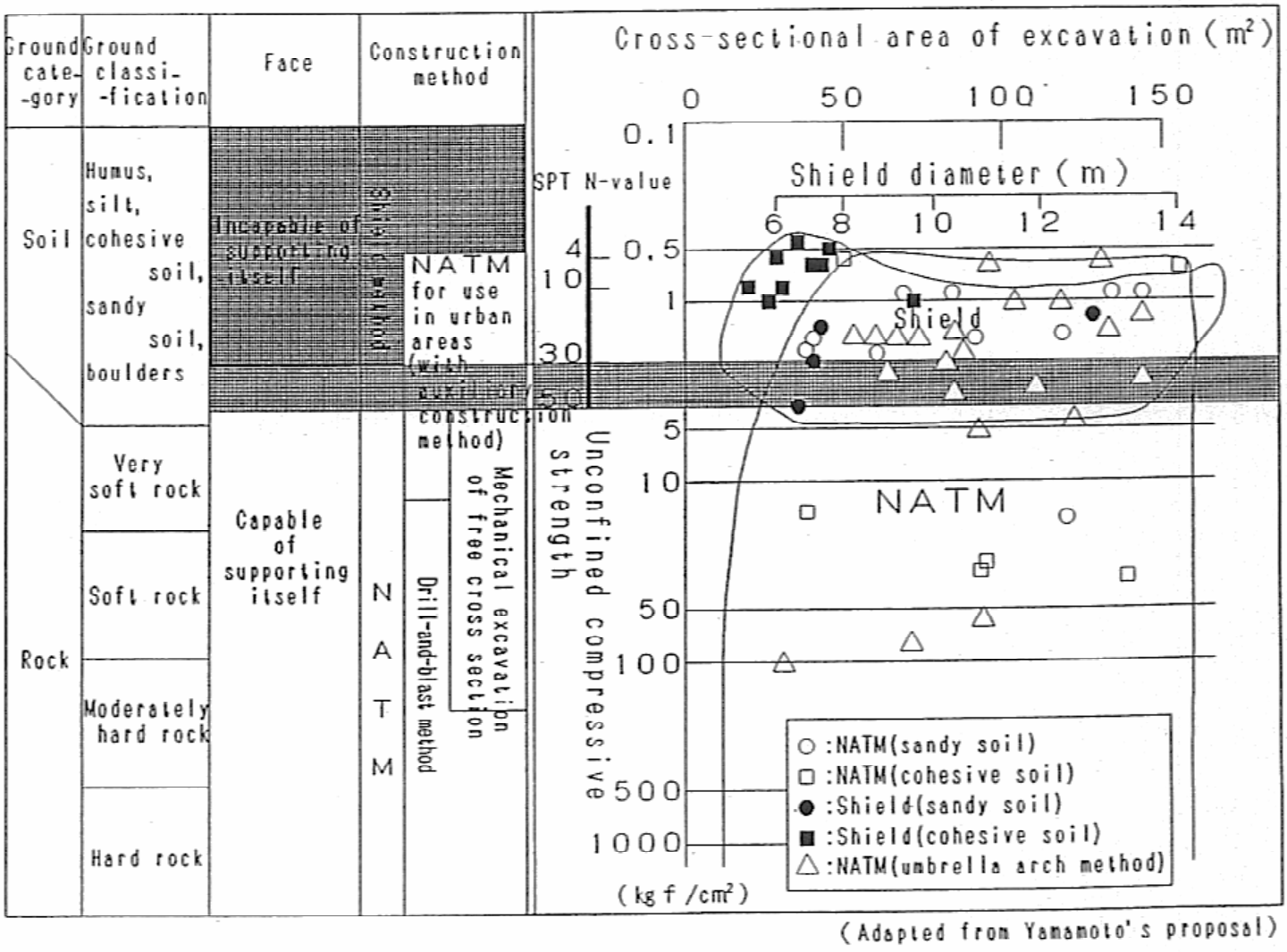

Fig. 3 Applications of tunneling methods in urban areas

2. CLASSIFICATION OF AUXILIARY CONSTRUCTION METHODS

Auxiliary methods of tunnel construction are classified, according to their purposes, into face stabilization measures, seepage control measures, surface settlement control measures, and adjacent structure protection measures. Table 1 shows the classification of auxiliary construction methods. Auxiliary construction methods often have double effects: primary effect and secondary effect. Two or more auxiliary construction methods are often used in combination.

Table. 1 Classification of auxiliary construction methods

Method		Purpose						Ground to which the method is applicable			Remarks
		Safety in construction				Environmental conservation					
		Face stabilization			Seepage control	Surface settlement control	Adjacent structure protection	Hard rock	Soft rock	Soil	
		Crown stabilization	Face stabilization	Foot stabilization							
Presupport	•Forepoling(hollow/filled-in type,grouting type)	◎	○				○	○	◎	◎	
	•Pipe roofing	○	○			◎	○		○	○	•
	•Horizontal jet grouting (jet grouting and mixing)	○	○			○	○			○	•
	•Long steel pipe forepiling(filled-in type,grouting type)	○	○			○	○		○	○	•
	•Prelining	○	○			○	○		○	○	•
Foot reinforcement at face	•Shotcreting		◎					○	◎	◎	
	•Rock bolting		◎					○	○	○	
	•Temporary invert			○		○			○	○	
	•Foot reinforcement bolting(piling)			○		○			○	○	(•)
Seepage control and ground reinforcement	•Drainage	○	○		◎			○	○	○	•
	•Drain boring	○	○		◎			◎	◎	◎	•
	•Deep well	○	○		○					○	•
	•Well point	○	○		○					○	•
	•Grouting	○	○	○	◎	○	◎	○	○	○	•
	•Vertical pre-reinforcement	○	○			○		○	○	○	•
	•Cut-off wall				○	○	◎			○	•

Note : ◎ : a method used commonly, ○ : a method used in some cases, • : a measure that cannot be executed with conventional tunneling equipment/ facilities or materials, or a measure that has a great impact on construction cycle

Table. 2 Types of umbrella arch methods

Category	Name of method		
	Steel pipe-based	Jet-grout column-based	Combined use of both
Presupport	Pipe roof, AGF, TREVITUBE	RJFP, TREVLJET, MJS	TREVI, RJFP
Foot reinforcement	AGP, MICROPILE	RJP, TREVLJET	TREVI, RJP
Site reinforcement	AGP, MICROPILE	RJP, TREVLJET	TREVI, RJP

3. PRESEN STATE OF AUXILIARY CONSTRUCTION METHODS

3.1 Background of the growing use of auxiliary construction methods

(1) Increase in the percentage of tunnel sections
- The number of projects in which newly constructed roads run through mountain areas or run across the generally slender Japanese islands (i.e., across mountain ranges) has increased.
- Design specifications have become increasingly stringent, making tunneling unavoidable because of alignment requirements.
- The number of cases in which tunneling must be used so as to avoid urban areas or built-up areas because of environmental measures or urban planning considerations.

(2) Growing need to apply the mountain tunneling technique to urban tunnel construction
- Mountain tunneling is less expensive than shield tunneling.
- Mountain tunneling is more environment friendly than cut-and-cover construction.
- Making changes in the shape and size of cross-section is easier in mountain tunneling than in shield tunneling.

(3) Increase in the number of large-section mountain tunnels and the growing use of auxiliary construction methods
- The number of projects for six-lane roads, and therefore the number of three-lane cross section tunnels, is increasing so as to cope with growing road traffic.
- A growing number of new tunnels, particularly tunnels in urban and suburban areas, are being planned to have a cross section large enough to accommodate walkways and other facilities.
- A growing number of plans call for large-section tunnels designed both for more space and for high-speed driving.
- A growing number of projects call for tunneling in poor ground, such as, portals (talus), fault fracture zones, and soil strata. Various auxiliary construction methods have been developed.

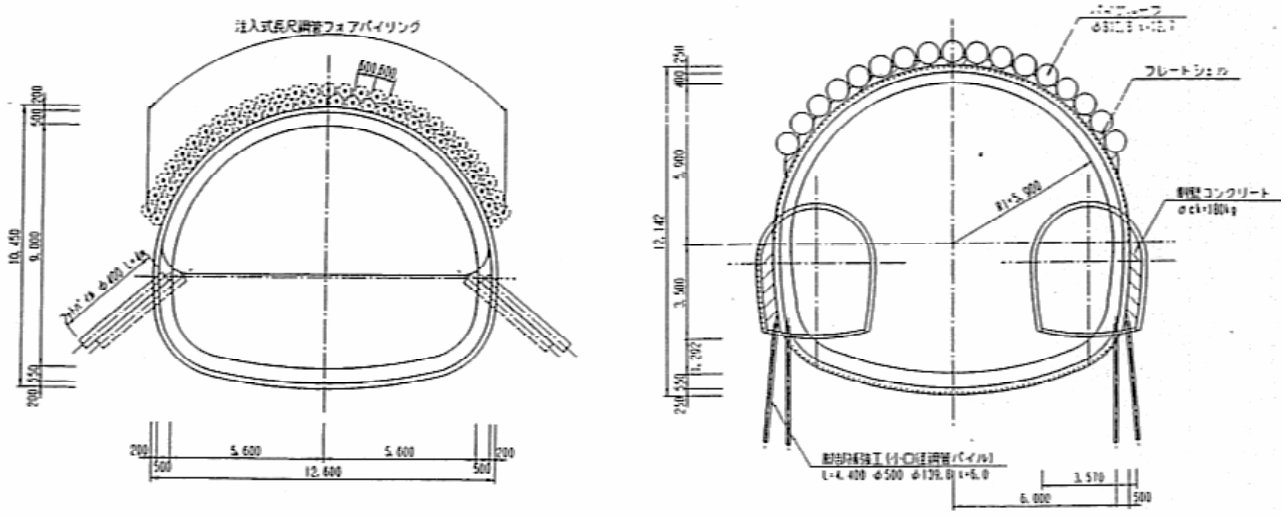

Fig. 4 Applications of auxiliary construction methods

3.2 Recent trends in umbrella arch methods

Table 3 shows the numbers of different umbrella arch methods adopted in recent projects. Recent trends are summarized below.

Table. 3 Umbrella arch methods adopted in recent projects in Japan (as of August 1998)

(As of August 1998)

Method	Site at which the method was adopted for the first time	Estimated number of sites where the method was adopted
RJFP method	Applied to Kokubugawa Tunnel in 1989 after introduced from Itary	14
Foot reinforcement method	Applied to Sakuma Tunnel in 1990 after introduced from Italy	75
AGF method	Applied to Futatsui Tunnel in 1992 after developed in Japan	300
Trevi method	Applied to Maiko Tunnel in 1993 after introduced from Italy	20
MJS method	Applied to Kozukayama Tunnel in 1994 after developed in Japan	20

(1) As shown in the table, umbrella arch methods have come into wide use.
(2) In about 60 to 70% of the cases shown in the table, an umbrella arch method of one kind or another was used as a means of portal stabilization. In the remaining cases, umbrella arch methods were used for face stabilization, environmental conservation, surface settlement control, etc.
(3) In most cases, portal zone works are three-shift works (length of single-shift works=12.5 m).
(4) Umbrella works in the tunnel are in most cases six- or seven-shift works.
(5) In cases where the number of shifts is small, the AGF method, which uses a jumbo readily available at the site, is adopted.
(6) In cases where many shifts are used, importance is attached to the efficiency of work in the umbrella arch method, and various construction methods are adopted.
(7) In cases where the bearing capacity achieved by the umbrella arch method alone is not sufficient, foot reinforcement is adopted. In cases where the working face is not self-supporting, rock bolts are used.

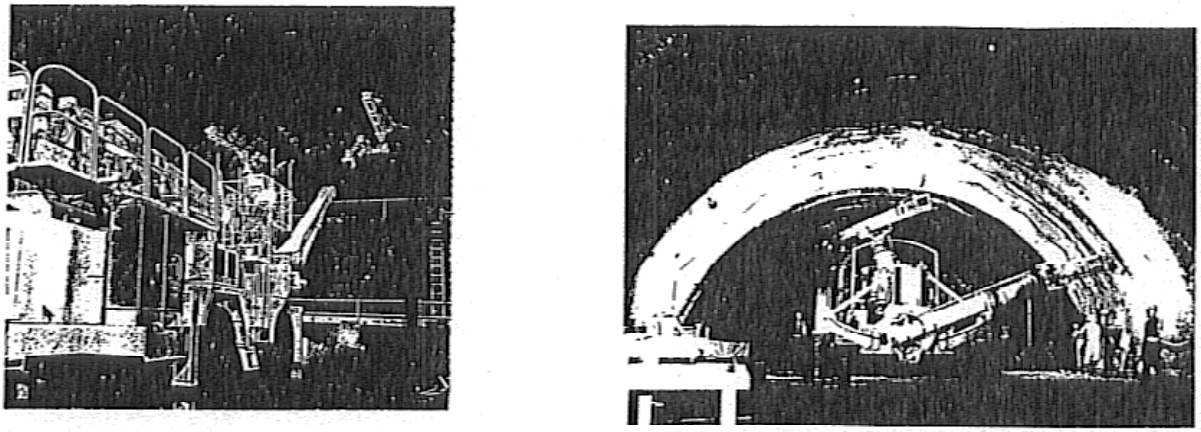

Photo. 1 Umbrella arch method

4. SELECTION OF AUXILIARY CONSTRUCTION METHODS AND TASKS AHEDAD

Usually, an auxiliary construction methods for a particular project is selected by the engineer concerned. By making comprehensive judgments based on empirical, engineering, and/or technical judgments, the engineer selects a method that he or she considers most appropriate for the project. The engineer's opinion is then compared with the opinions of other engineers involved in the same tunnel project, and a final decision is made as to which method to use.

It is not unusual that the engineers disagree with one another. This is because different engineers have different experiences with tunnel construction and are in different functions or positions. In order to select a more rational auxiliary construction method and ensure safety and economy of construction, it is important to know each engineer's selection criteria and opinion about different auxiliary construction methods and to reconcile disagreement and differences in opinion about auxiliary construction methods among the engineers concerned. As a means of attaining this goal, the development of rational procedures for auxiliary construction method selection and of selection criteria is hoped for.

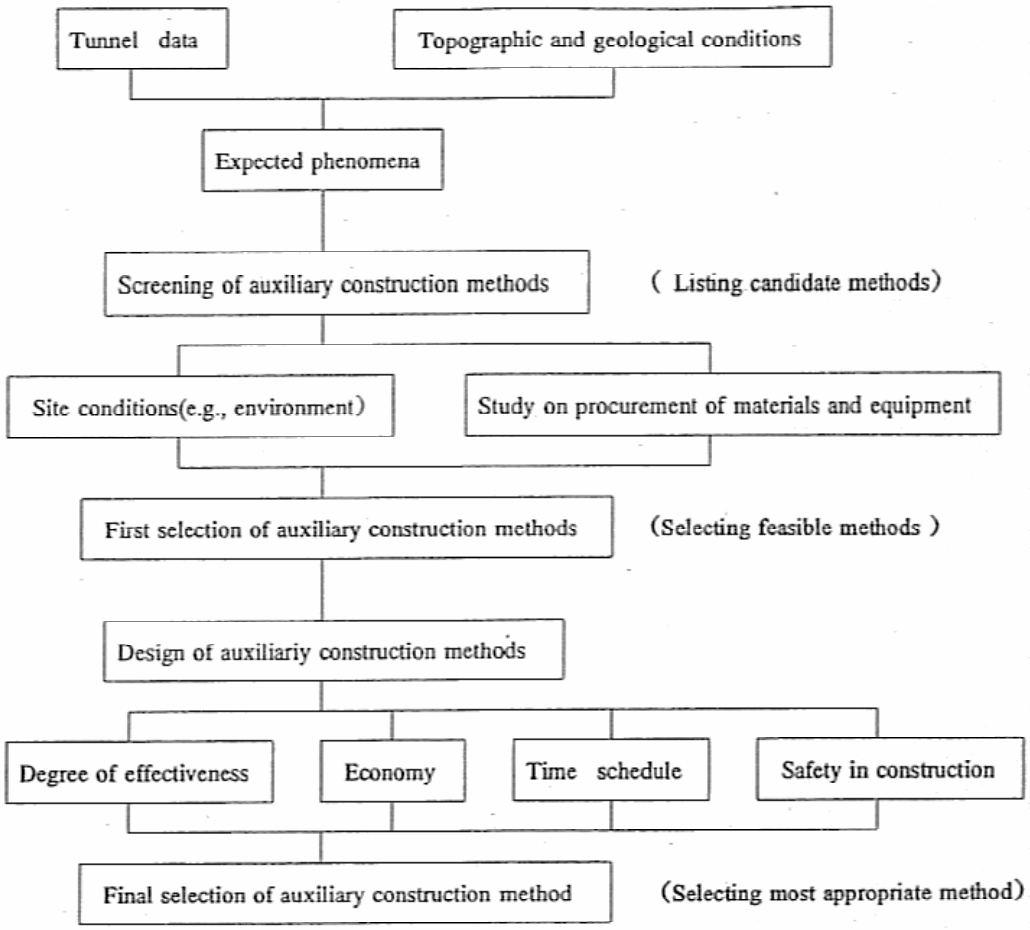

Fig. 5 Example of a procedure for selecting an auxiliary construction method

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